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TITLE: **T-shaped Broadband CPW – fed folded-Slot Antenna for 5.8 GHz RFID Applications**

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COMMENTS AND EXPLANATION:

REVEIWER 1 COMMENTS:

COMMENT 1 All sections of your paper not related to the antenna design, like page 1 and the first half of page 2 must be removed.

Explanation/Modification: **Page 1 and first half of page 2 has been removed. The new content related to antenna design has been added.**

***COMMENT 2*:** The photo on Figure 2 is of poor quality and has the wrong aspect ratio. A paper containing bad quality photos and/or graphics cannot be published.

Explanation/Modification: **The photo on Figure 2 has been replaced by good aspect ratio.**

***COMMENT 3*:** Actually it was Peterson (IBM Journal RD) who first demonstrated a MEMS switch and no Goldsmith et al as suggested.

Explanation/Modification: **Our proposed antenna is implemented with the substrate size L x W = 16.5 x 20 mm. The other paper proposed antenna with the size is compared as below before proceeding with this work.**

Paper detail	Antenna size
A Compact CPW-Fed Omni-Directional Monopole Antenna For WLAN And RFid Applications, Progress In Electromagnetics Research Letters, Vol. 32, 91-99, 2012	**28 x 26 mm^2**
Wideband Compact CPW-Fed Circularly Polarized Antenna for Universal UHF RFID Reader, IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 63, NO. 9, SEPTEMBER 2015	**120×120×0.8mm^3**
Dual-Band CPW-Fed Transparent Antenna for Active RFID Tags, IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 14, 2015	**36x39x0.175mm^3**

The antenna size will be reduced in the future work.

COMMENT 4: An antenna built on a lossy laminate like FR4 will burn in a matter of seconds if driven by 100W RF at 5.8GHz.

Explanation/Modification: **We have tested our proposed antenna with different substrate like FR4, Teflon, Rogers RT/Duroid and Quartz through simulation. Among these substrate materials, wide operating bandwidth is obtained for FR4 substrate. Since we have concentrated in getting resonant frequency at 5.8 GHz with better return loss and**

VSWR properties, we choose FR4, low cost, and easily available substrate material for RF applications spanning from 100MHz up to (6-7)GHz (L,S, and C bands) and when applying the FR4, the surface of you antenna will be smoother.

To fulfill our aim of getting wider bandwidth, we have not considered the loss and simulated the efficiency. This will be concentrated in the next our work by choosing the better substrate material

***COMMENT 5*: The antenna efficiency is neither simulated nor measured. What are the dielectric losses and what are the copper losses in the FR4 laminate.**

Explanation/Modification: Antenna efficiency has been calculated, plotted and included in the paper.

For antennas and microwave circuits we are often interested in finding resonances. And the resonance frequencies are independent of the finite conductivity and no shift in frequency with respect to losses. Since we have concentrated in getting the resonance at 5.8 GHz we have fabricated the proposed antenna in FR-4 substrate having advantages such as inexpensive and easily available.

At high frequencies, dielectric loss is dominant, and is dependent on the dissipation factor (loss tangent) for a given dielectric material. The dielectric constant and loss factor are two of the most significant parameters that affect the performance of PCB circuits FR-4 has dielectric constant (er) of 4.4, loss factor tan δ of 0.035 and dielectric strength of 70 (breakdown) MV /m. For FR-4 at 1GHz, the total loss is about 0.213 with copper and dielectric losses of 0.09 and 0.123 respectively.

***COMMENT 6*:** Plotting only the magnitude of the impedance abs(Z) without knowing its phase does not have much sense.

Explanation/Modification: **It is typical to define the impedance bandwidth of an antenna as containing the range of frequencies in which return loss is below -01 dB. Our aim is to project the resultant impedance (50.275 ohm at 5.8 GHz) for RFID application which is very close to the ideal transmission line. However the impedance of the antenna changes with frequency, resulting in a limited range that the antenna can be matched to the transmission line. Since the variation of impedance in terms of frequency plays major role in impedance matching, we have concentrated only in amplitude plot. The phase plot of impedance will also be included in the forthcoming our research papers of antennas.**

***COMMENT 7*:** Why is the simulated current distribution non symmetrical on a purely symmetrical antenna structure?

***Explanation/Modification*:** **Due to cross polarization in our antenna as much, the current distribution is asymmetrical instead of symmetrical. Due to impedance mismatch between the feeding transmission line and the proposed antenna, we have asymmetrical current distribution. This will be rectified in the future work.**

COMMENT 8**:** What is co/cross polarization, if no coordinate system nor desired polarization of the antenna is specified?

Explanation/Modification: **The polarization of an electromagnetic wave is defined as the orientation of its electric field vector. The desirable component, having the intended sense of rotation (right, or left), is called the copolarization component. The undesirable component, with the opposite polarization, is called the cross polarization component.**

For an RFID application cross polarization needs to be as low as possible outside the antenna sectoral coverage in order to avoid reading tags outside the beam width.

COMMENT 9**:** What are the effects of the SMA connector and feeding cable since the currents on the proposed structure are not balanced? Both the SMA connector and the cable probably contribute to the radiation?

Explanation/Modification: Yes. We have impedance mismatch due to cable and connector feeding part, which introduces the asymmetry in current distribution and introduces cross polarization effect also.

T-shaped Broadband CPW – fed folded-Slot Antenna for 5.8 GHz RFID Applications

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***Abstract*— A novel design of T-shaped broadband CoPlanar Waveguide (CPW) – fed folded slot monopole antenna is proposed for the application of Radio Frequency Identification (RFID) at 5.8 GHz. The proposed antenna is fabricated on FR-4 substrate and having the size of 16.5 mm x 20 mm. The bandwidth of 30.17% and peak antenna gain of more than 4.15 dBi has been achieved from the proposed antenna through simulation and testing. The fundamental parameters of antenna which meets the acceptable standards are measured. The radiation pattern of broadside and bidirectional in E-Plane and omni directional in H plane are also observed**.

***Index Terms*— RADIO frequency identification, folded slot monopole antenna, bandwidth, gain, radiation pattern.**

I. Introduction

The passive ultra high frequency (UHF) radio frequency identification (RFID) technology has been widely deployed in logistics and security applications, and actually is evolving for sensor networks and Internet of Things (IoT) paradigm [1],[2].Several frequency bands have been assigned to the RFID applications such 125 kHz, 13.56, 869, 902-928 MHz, 2.45 and 5.8 GHz [3]. The reader antenna is one of the important components in the RFID system. To enlarge the coverage for the RFID system, there are several potential antenna designs with a compact size and good radiation performance to be embedded inside a handheld reader device as an internal antenna [4]. Two meander monopole antennas [5], [6] and a slotted-ground patch antenna [7] were suitable for handheld reader operation due to their small sizes. In order to design a low-profile handheld reader, both a loaded planar inverted- F antenna (PIFA) [8] and a folded shorted patch [9] have earned high attention.

Apart from the characteristics of low profile, low cost, and easy to make, slot antennas also have the advantage of wide bandwidth. The slot antennas can be fed by microstrip line, slot line and CPW. In this paper, we presented the design of slot antenna fed by CPW. Slot antennas are popular omnidirectional microwave antennas [10]. These antennas feature omnidirectional gain around the azimuth with horizontal polarization. Slot antennas exhibit wider bandwidth, lower dispersion and lower radiation loss compared to microstrip antennas.

Two similar coplanar waveguide (CPW)-fed broadband CP slot antennas have been proposed in the literature [11], [12]. Both antennas have wide rectangular slots, with two inverted L-shaped grounded strips placed around the opposite corners of the slots to produce circular polarization. Recently, a design which can be applied to broadband CP antenna UHF RFID systems was proposed [13]. In [14], an annual plate with a rectangular slot was introduced at the radiating element to make the antenna operate in dual band. The slot has been located at the area in order to reduce current distribution. Therefore, the slot must be carefully designed to ensure successful performance of the antenna.

In literature, several antenna designs for RFID applications have been proposed, including the meander line structure [15] and the aperture-coupled structure [16]. These antennas are either too large in size or too complex in structure for practical applications. Broadband CPW-fed folded-slot monopole antennas for 5.8 GHz RFID application have been proposed in [17], [18], [19, 20] and [21]. From these papers, we learn that, by properly selecting a folded slot on a rectangular patch, compact antenna size, broad impedance bandwidth and good radiation characteristics suitable for the RFID applications at microwave frequency range could be achieved.

Because of the slot antenna's wideband characteristics square slot antenna with coplanar waveguide (CPW) feed lines [22] and CPW-fed triangular patch antennas [23] are demonstrated in the literature. In general, the wideband CPW-fed slot antenna can be developed by tuning their impedance value. Several impedance tuning techniques are reported in literatures by varying the slot dimensions. These tuning techniques have been carried out with various slot geometries like bowtie slot [24] and wide rectangular slot [25]. Though large impedance bandwidth could be obtained from the above techniques, their complexity is quite high. In general, two parameters affect the impedance bandwidth of the planar slot antenna, the slot width and the feed structure. The wider slot gives more bandwidth, and the optimum feed structure determines good impedance matching [26]. The CPW feed line with various possible patch shapes, such as T, cross, forklike, volcano and square are used to obtain wider bandwidth [27].

So, in this paper we envisage the possibility of designing the CPW-fed folded-slot antenna for RFID applications around resonant frequency of 5.8 GHz, with sufficient bandwidth of operation and omnidirectional radiation patterns.

In this paper we propose the design the RFID tag antennas using CPW-fed folded slot technology so that the designed antenna operates around 5.8 GHz. Also the antenna should offer a wide band width around the resonant frequency. The design details of the proposed antenna both in experimental and theoretical results are presented below for discussion.

II. Antenna Configuration

In the application of CPW for antenna design, a radiating element is constructed from a conventional CPW by widening the center strip conductor to form a rectangular or square patch [28]. This patch produces a single-lobe, linearly polarized pattern directed normal to the plane of the conductors. The CPW is the feeding which side-plane conductor is ground and center strip carries the signal. The advantage of CPW fed slot antenna is wideband antenna which many research introduce the several shape of slot antenna for use in WLAN applications. CPW has also gained the advantages of lower cross polarized radiation from the feed over conventional microstrip patch antenna. We have used the CPW with 50 ohms as the feed line for our proposed antenna in order to match the characteristic impedance of transmission line. The configuration of proposed T-shaped broadband CPW) – fed folded slot monopole antenna operating in 5.8 GHz RFID tag is shown in fig. 1. 5.8 GHz tags are compatible with CMOS technology CMOS technology presents multiple advantages:

1) Low-cost and mature technology
2) Low-bias voltage (< 3V, even below 1V for SOI MOS)
3) Low power consumption (portable applications)
4) Mixed analog-digital circuits (one-chip) can be built
5) High levels of integration can be reached
6) Compatible with micromachining techniques (MEMs)

The antenna simple structure is based on a one layer FR-4 dielectric substrate only, which has 16.5 mm length and 20 mm width. This common substrate and metallization can reduce the cost of the tag and it can easily integrate the antenna with the Printed Circuit Board. It is worth mentioning that the dielectric superstrate can also function as a protecting cover from catastrophic environment. The antenna is fed by a SMA 50 Ω coaxial connector. The main advantage of the coaxial connector is that it can be placed at any desired location inside the antenna in order to match with its input impedance.

The design optimal geometrical parameters are shown in Fig.1. For the dielectric constant ϵ_r = 4.4, Substrate thickness h=1.6 mm, trace width, W_I= 3.6 mm, Ground plane spacing, g= 0.4 mm, we get characteristic impedance, Zo of the feed line as 49.97 ohms. The width of strip and slot of the 50 ohm CPW feed line, s and g are chosen as 3.6 mm and 0.4 mm respectively. The two ground planes are placed symmetrically on each side of the CPW line.

In the folded slot antenna, the resonant conditions are developed from the circumference, which is proportional to the guided wavelength. The input return loss & the resonant frequency of the proposed antenna can be varied with total length L, width W and spiral strip on the substrate. To facilitate the design and the fabrication process let us select length and width of the rectangular patch to be slightly larger than half the wavelength corresponding to the resonant frequency, that is substrate size L x W =

16.5 x 20 mm. The vertical spacing between the strips and ground plane is adjusted to obtain good impedance matching.

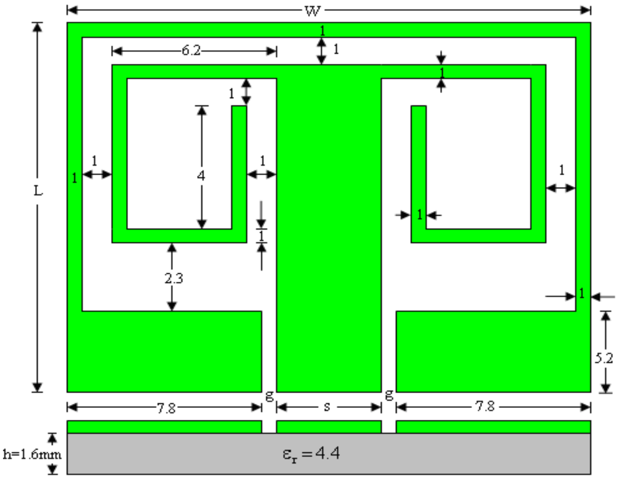


Figure. 1. Proposed CPW- fed folded - Slot T Shaped broadband Antenna (All dimension are in mm)

We first studied the dimensions of the antenna with the simulation tool based on the method of moments ZELAND IE3D version 12.0 and then adjusted them by experiments. Finally the dimensions of the fabricated antenna were chosen to be width of 20 mm and height of 16.5 mm as in fig. 1. The prototype of fabricated antenna has been shown in fig. 2.

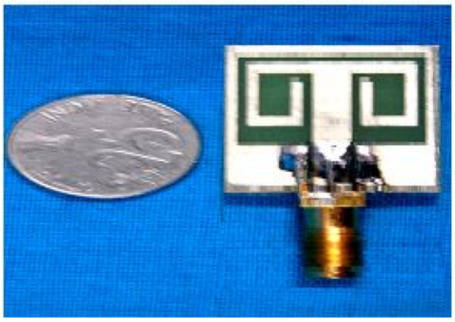


Figure. 2. Photograph of the fabricated antenna for 5.8 GHz applications

III. Results and Discussions

Based on systematic comparative studies by means of simulation using full-wave, method-of-moments-based electromagnetic simulation IE3D software, a set of suitable geometric parameters for the antenna is designed, such that the antenna operates around 2.45 GHz band with a sufficient impedance bandwidth. The optimal parameters in all angles are represented in fig.1 for 5.8 GHz prototype antenna. This antenna is implemented with the substrate size L x W = 16.5 x 20 mm and is fabricated on an FR- 4 substrate with dielectric constant $\varepsilon_r = 4.4$ and thickness of 1.6 mm.

A. VSWR Vs Frequency

A high VSWR is an indication the signal is reflected prior to being radiated by the antenna. VSWR and reflected power are different ways of measuring and expressing the same thing. A VSWR of 2.0:1 or less is often considered acceptable. Most commercial antennas are specified to be 1.5:1 or less over some bandwidth. Based on a 100 watt radio, a 1.5:1 VSWR equates to a forward power of 96 watts and a reflected power of 4 watts, or the reflected power is 4.2% of the forward power. Our designed antenna has the VSWR of 1.0 at the desired 5.8 GHz frequency which is very closer to the ideal antenna performance as shown in fig.3.

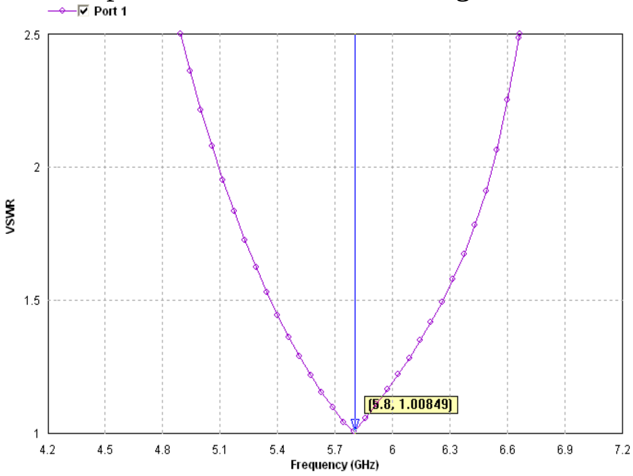


Figure. 3. Proposed CPW-fed folded spiral strip Antenna VSWR versus Frequency

B. Return loss Vs Frequency

The return loss (S_{11}) of -48.68 dB for the resonant of measurement at 5.8GHz with 30.17% bandwidth of (4.93-6.68 GHz) for -10dB below was observed. It can be clearly seen from the return loss graph that the antenna resonates at desired frequency that is at 5.8 GHz, which is one of the operating bands for the RFID applications.

The reflection coefficient (S_{11}) reach a value of less than -48.68 dB in the resonant frequency at 5.8 GHz which is implies that the antenna is well suited for this RFID application.

Fig.4 depicts the comparison results between measured and simulated return losses of the proposed antenna. The solid and the dashed lines denote the simulated and measured return losses, respectively. The measured return loss curve shows that the proposed antenna is excited at 5.8 GHz with a -10 dB return-loss bandwidth of 1.38 GHz (5.11–6.49 GHz). The maximum return loss of -48.68 dB is obtained at the resonant frequency 5.8 GHz. The simulated bandwidths have better return loss performance from 4.93-6.68 GHz in the bandwidth of 1.75 GHz. From these results, it can be demonstrated that this antenna is satisfied with the 5.8 GHz RFID applications.

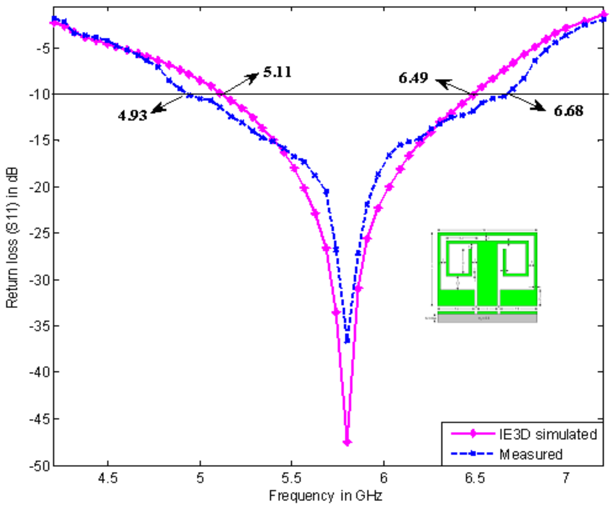


Figure. 4. Measured and simulated frequency responses of input return loss for proposed antenna

C. Antenna input impedance Vs Frequency

Impedance bandwidth 30.17% in (4.93-6.68 GHz) for -10dB below can fulfill the typical bandwidth requirement for the RFID applications. This bandwidth is sufficient enough for RFID applications around 5.8 GHz and small enough to prevent interference to other wireless applications in between 5 GHz and 6 GHz band. These results show the better impedance matching which is shown in Fig. 5.

This is achieved by properly calculating the fundamental parameters of CPW and the spacing between the centre and inner spiral strip slot structure.

D. Efficiency

The simulated antenna efficiency is shown in Figure 6. The proposed antenna shows above 90% efficiency over the entire bandwidth which is most desirable for RFID applications. Here the optimum efficiency should be 75% for radiating antenna, which means radiating power should be 75% of the input power feeding to antenna. The maximum antenna efficiency 98% is obtained at 5.8 GHz.

E. Current distribution

The simulated current distributions of the CPW - fed spiral strip slot antenna at the frequencies of 5.8 GHz are illustrated in Fig. 7. It is observed that the current is concentrated more on the CPW line the edge of the slot and the spiral strip feeding stubs, where both x- and y-components of the currents exist. The current distribution is relatively stable over the operating frequency range, which indicates that the radiation characteristics are to be stable as well.

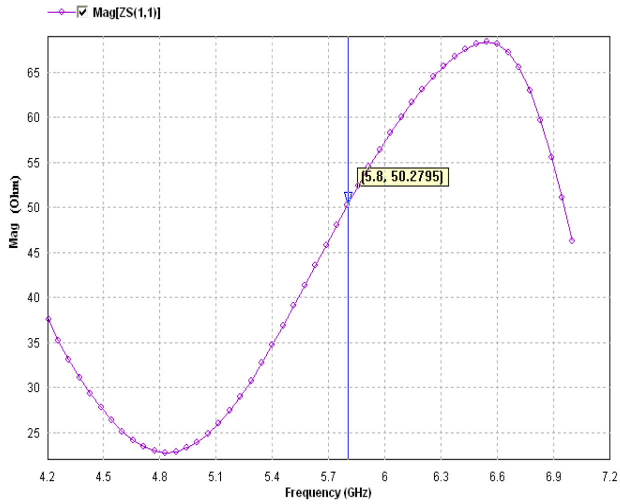


Figure. 5. Proposed CPW-fed folded spiral strip Antenna Impedance vs. frequency

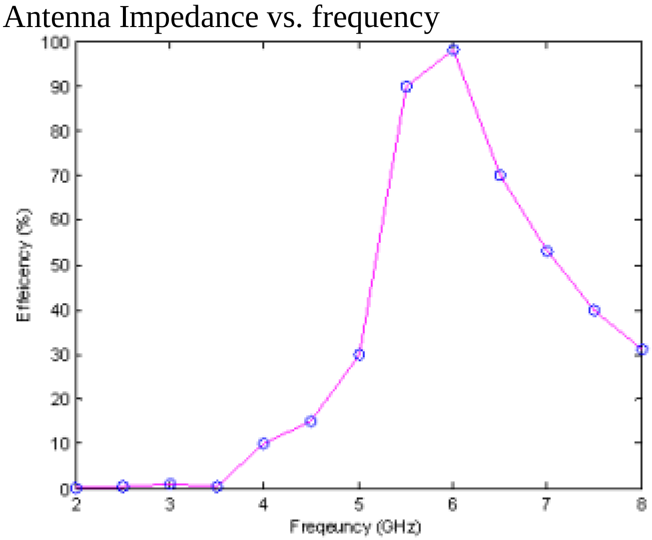


Figure. 6.Proposed antenna efficiency Vs. frequency

Note that the y-component of the current on the centre strip of the CPW line is of the same magnitude and out of phase with that of the current on the adjacent ground plane. In addition, the x-component of the current on the CPW line, the ground, and the spiral strip -shaped feeding stubs is of same magnitude and out of phase with respect to the centerline (y-axis) because of the configuration symmetry of the antenna.

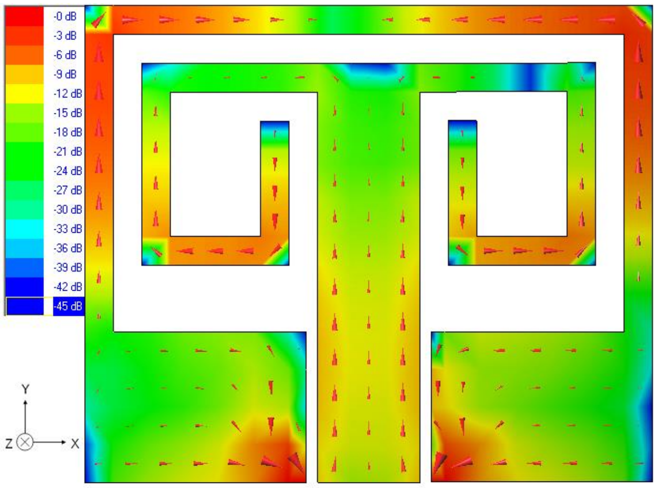


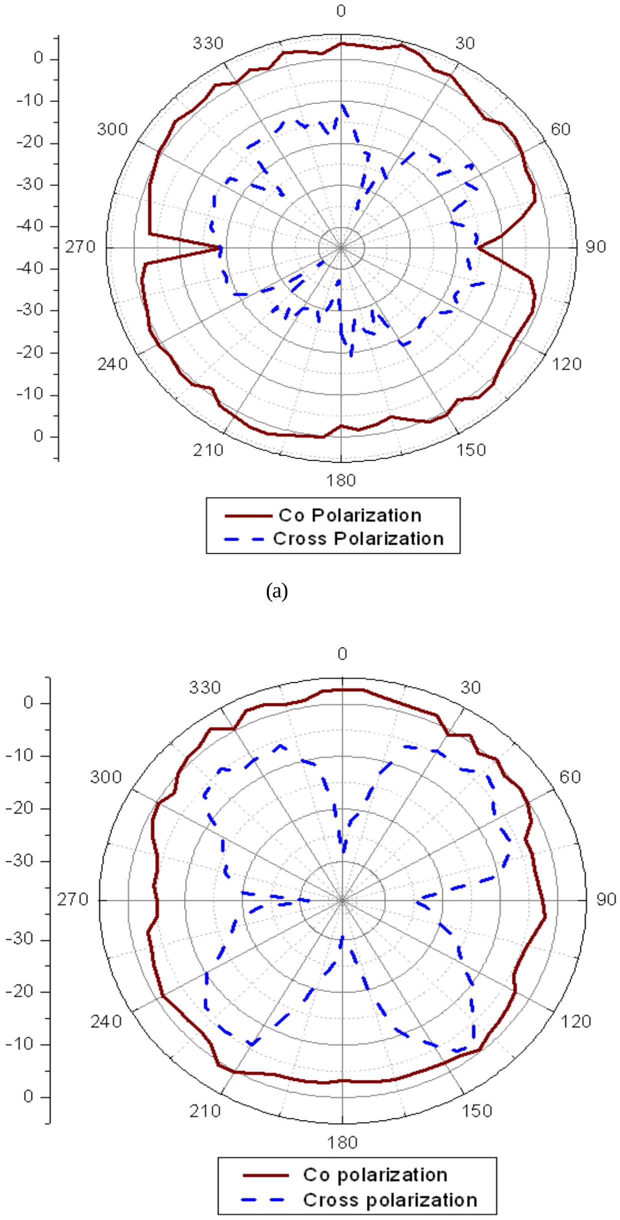
Figure. 7. Current distribution of Proposed CPW-fed folded spiral strip antenna

F. E and H plane radiation pattern

The radiation comes from these current components will cancel out each other in the far-field zone and thus do not contribute to the co-polar radiation. Instead, they contribute to cross-polar radiation. It can be concluded that the radiation of the proposed antenna is mainly determined by the y-component of the current on the spiral strip feeding stubs and the folded ground.

The polarization of an electromagnetic wave is defined as the orientation of its electric field vector. The desirable component, having the intended sense of rotation (right, or left), is called the copolarization component. The undesirable component, with the opposite polarization, is called the cross polarization component. For an RFID application cross polarization needs to be as low as possible outside the antenna sectoral coverage in order to avoid reading tags outside the beam width.

Fig.8 plots the measured far field radiation pattern at 5.8GHz for the designed antenna. It can be observed that E-plane radiation pattern is co polarization with shape 8 in the two frequencies. At 5.8 GHz, the shape of the E- plane radiation pattern is slightly distorted. The H-plane radiation pattern in coploarization (which is desirable) on the other hand is purely omnidirectional. Hence, this T-shaped monopole antenna demonstrates a consistent radiation pattern in the desired band of frequencies. The losses due to cross polarization which is undesirable should be reduced in further analysis.



(a)

(b)

Figure. 8. Radiation pattern of the proposed CPW-fed folded spiral strip antenna (a) E-plane (b) H-Plane

G. Gain of proposed antenna

Broadside and bidirectional radiation pattern in the E plane and almost omnidirectional in the H plane were observed. The radiation characteristic of this design is found to be stable since similar patterns have also been measured at other operating frequencies across the band. The antenna peak gain of 4.15 dBi and 4.17 dBi at 5.8 GHz for the measurement and simulation respectively were also achieved as shown in fig.9. Finally, we also noticed that the proposed antenna structure has sufficient bandwidth to cover the requirement of both wireless local area network

(WLAN) standards in the 5.2 GHz and 5.8 GHz RFID systems.

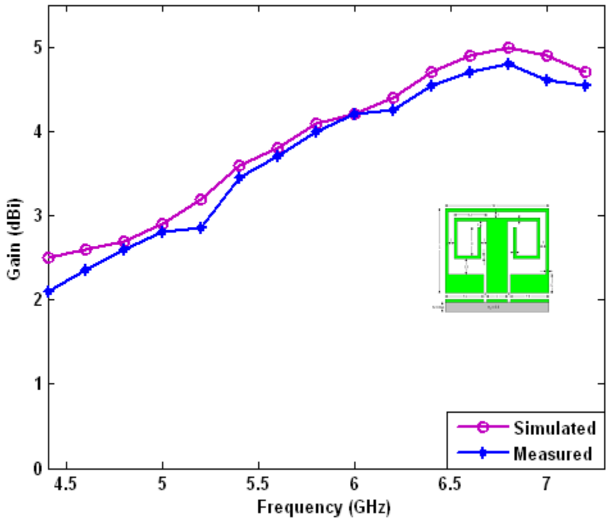


Figure. 9. Measured and Simulated antenna gains for proposed antenna

IV. CONCLUSION

A compact, low profile, single layer CPW – fed folded - spiral strip slot monopole antenna has been proposed & implemented. The experimental results shows that the proposed antenna has generalized bandwidth of 30.17% with antenna gain more than 4.15 dBi. This antenna can be easily mounted and has good compatibility with other microwave circuit components. This antenna is mechanically robust, easy to fabricate and integrate with practical circuit. The proposed antenna is simple to design and compact in size. It provides broadband impedance matching, consistent omnidirectional radiation patterns and appropriate gain characteristics in the RFID frequency region. Furthermore, this antenna has many advantages such as easy fabrication and low cost. Hence the proposed antenna can be used for WLAN 5.8 GHz communication system along with RFID application.

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Dr.P.Thiruvalar selvan his Ph.D. degree in the area of Microwave antenna optimization using neural networks under the guidance of Dr.S.Raghavan from the Department of Electronics and Communication Engineering at National Institute of technology, Trichy. She has more than 15 years of teaching experience in various reputed Engineering colleges. His research interest includes Microwave antenna design, Microwave Integrated Circuits, Numerical Techniques of Microwave and Millimeter wave transmission lines using neural network & MATLAB. He has published 60 research papers in various national and International level Conferences and Journals. He is the Life Member in ISTE.

Dr.S.Raghavan having more than 30 years of Teaching (U.G., P.G. and Research) experience in National Institute of technology, Tiruchirappalli, India as a Senior Professor. Obtained Ph.D.(Microwave Integrated Circuits) from I.I.T., Delhi, India under the guidance of Prof.Baharathi Bhat and Prof.S.K.Koul. He has developed Microwave and Microwave Integrated Circuits Lab. Senior Member of IEEE in MTT and EMBS. Life Fellow in BES. Fellow in IETE and IE, Life member in ISSS, MRSI, ISTE, EMC/EMI, IELTS and ILA. Referee for MTT journal. Carried out two Research and Development projects of Coplanar Waveguide and RF-MEMS. Has contributed more than 100 papers in international Conferences and five international Journals. Conducted more than 10 tutorials in IEEE preconference tutorials.